Timidity

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Timidity: A Useful Emotional Mechanism for Robot Control? - PAPER IN REVIEW - PLEASE DO NOT DISTRIBUTE

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Responses labelled as emotional in the higher animals are frequently portrayed as incidental to the generation of reasonable behavior. Clearly this view is incompatible with the reality of animal behavior as observed in nature, emotion plays a significant role in the generation of useful behaviour. Homeostasis is the product of the interaction of the nervous, endocrine and immune systems. This work views emotional responses as part of an integrated approach to the generation of behavior in artificial organisms via mechanisms inspired by homeostasis. The mechanism presented here employs the concept of a novel Artificial Endocrine System which interacts with an Artificial Neural Network to generate behaviour which could be classified as emotive.

1 Introduction

The quest for more effective techniques in the implementation of intelligent systems has lead to the consideration of many mechanisms of both human and non-human cognition as potential models for behaviour generation. Artificial systems which attempt to capitalise on the use of emotional state information in the generation of behaviour have usually concentrated on symbolic representations and manipulation at the level of beliefs, desires and actions [12]. Much sub-symbolic work has assumed that the emotive state of a system is an emergent property rather than a controlling factor [2]. This work proposes a sub-symbolic mechanism for the explicit representation of emotive states as hormone concentrations which modify the behaviour of an artificial neural network (ANN). This mechanism is viewed as part of a more ambitious and general approach to the generation of intelligent behaviour centred around the biological concept of homeostasis [16].

The generation of intelligent behaviour in robotic systems has been a goal for many years. Some major advances have been made by borrowing ideas from biological organisms, but the generation of systems which can remain independent from human intervention for long periods of time is still largely unfulfilled. The applications for such systems grow more demanding with time and cry out for novel approaches to long term control of autonomous behaviour.

2 Biological Background

It is necessary to spend a little time examining the biological motivation for this work. To this end, the paper will explore (at a high level) the biological systems that help to maintain homeostasis within an organism. From there, it will be possible to move into the artificial domain, adopting useful metaphors from the biological system.

2.1 Mechanisms for Biological Homeostasis

Homeostasis is the ability of an organism to achieve a steady state of internal body function in a varying environment. Homeostasis is achieved via complex interactions between a number of processes and systems within organisms, namely the nervous system; the endocrine system and the immune system. By examining these systems and their interactions, we hope to emulate aspects of this behavior in artificial systems.

2.1.1 The Nervous System

The nervous system (NS) is central to an organism's ability to process and act upon stimuli that it receives from an external source. Organisms ranging from slugs to humans are endowed with a nervous system which ranges in size, ability and function. This system will then develop and improve over the lifetime of the organism, via processes such as learning and memory (although not exclusively these).

An organism will be exposed to a vast number of stimuli, to which it must react. Simply put, the NS will take sensory input and generate effector output. The sensory parts of the NS take input from vision, taste etc., which are stimuli for effector elements such as muscles. The processes seen in the NS have inspired artificial systems (artificial neural networks)[7] which form an integral part of the work proposed in this paper. The interaction between the NS and the endocrine system is complex and incompletely understood, but for the purposes of this work a simplistic model of neural stimulation and inhibition by hormones is employed.

2.1.2 The Endocrine System

Within an organism, chemicals known as hormones implement a regulatory mechanism acting directly at an individual cell level. This system, the endocrine system, is responsible for the production and storage of these chemicals [15]. Hormones are also produced by neurons and immune cells such as T-cells, but for the current purposes these mechanisms will be ignored. These hormones have a great deal of influence over a large number of bodily functions and are key actors in the maintenance of homeostasis. Hormones have many functions which affect behavior, assist growth, drive reproduction and so on. Typically, production of a hormone is in response to a change in state of the organism. Such changes are detected via the nervous system, immune system or by changes in other hormone or metabolite levels. Hormones are released into the blood or lymph system and are able to reach virtually all the tissues within the organism. It is quite possible (and normal) that there will be a number of different hormones present in the blood or lymph at any one time. However, not all cells will react to all hormones, as the response to hormones is highly specific: only certain cells are capable of responding to certain hormones. When a hormone locates its particular target cell, a binding takes place through specific receptors on the cells. Receptors on the target cell are usually located in one of two sites: within the cell nucleus (steroid hormone receptors) or in the plasma membrane (non-steroid hormone receptors, e.g., proteins, amines, and peptides). Non-steroid hormones decay and are ultimately removed from the organism at various rates. Built into the system is a mechanism by which hormones such as these will decay. This decay rate may well be a few minutes, but could potentially be a number of days. When a hormone binds with a receptor on the cell membrane, it stimulates internal signals to the appropriate sites within the cell, which in turn alter the cell's activity. For this work the only mechanism for hormone production which is considered is the change of external environment inducing the production of hormone analogous to short-lived non-steroidal substances which affect neuro-transmission.

2.1.3 The Immune System

The immune system is a remarkable, but complex, natural defence mechanism, which responds to foreign invaders called pathogens. Organisms typically have two lines of immunity, innate (inherited at birth) and adaptive (also known as acquired) which develops over the lifetime of the organism [14]. Pathogens are first attacked by the innate immune system, and if this defence by the innate immune system fails, then the pathogen is passed over to the adaptive immune system. The adaptive immune system primarily consists of B- and T-lymphocytes (cells). Through re-

ceptors on the cell, they are capable of binding with pathogenic material (antigens). Whilst the immune system is integral to the achievement of homeostasis, for the purpose of work presented in this paper, discussion of immune operations will not be considered further, as no attempt has been made at this point to integrate an AIS into the device.

2.2 Interactions between Biological Systems

So far, attention has been given to three systems within an organism: the nervous system, endocrine system and immune system. These systems do not act independently but as one large and complex system.

Work in [3] examined the mechanisms by which these three systems interact and can be summarised as follows (for a more in-depth analysis's see [5]): Immune, neural and endocrine cells can express receptors for each other and products from immune, neural and endocrine systems can exist in lymphoid, endocrine and neural tissues. This allows for interaction and communication between cells and molecules all three ways. The action of various endocrine products on the neural system is accepted to be an important stimulus of a wide variety of behaviors. These range from behaviours such as flight and sexual activity to sleeping and eating.

3 A Framework for Artificial Homeostasis

The concept of a *framework* is often employed when attempting to construct complex systems such as these. A framework could be said to consist of building blocks, which when combined, form a complete system, and indeed work in [5] proposed a potential framework for Artificial Immune Systems (AIS), and made allusions to the fact that Artificial Neural Networks could also be thought of in such a way. The authors argued that a framework would consist of (1) a representation of the components of the system (2) mechanisms by which to evaluate interactions of these components and (3) procedures for adaptation. Under such a conceptualisation, it is easier to discuss how such systems may be combined to form a more complex system. Table 1 captures the salient features of this argument, with the addition of the Artificial Endocrine System (AES). It is proposed that combinations of these components, will be useful in the construction of systems capable of artificial homeostasis. Work in this paper is restricted to the use of a combination of ANN and AES.

	ANN	**AES**	**AIS**
(1)	Neuron	Endocrine gland	Lymphocyte
(2)	Network topology	Hormone interactions	Affinity measures
(3)	Learning algorithms	Hormone structure update	Immune algorithms

Table 1: ANN, AES and AIS in a simple framework, see text for definition of (1), (2) and (3)

3.1 Artificial Counterparts of the Biological Systems

Significant work has been done in extracting useful metaphors from the nervous system for the creation of artificial neural networks [7]. Work is now emerging in the field of AIS [5], but little has been done on AES. This section will discuss ANN and AIS and postulate that through the combination of these approaches and an AES it may be possible to create an artificially homeostatic system. Work in [5] describes some of these ideas, and the reader is directed to there for further detail on interactions of both the biological and artificial systems.

3.1.1 Neural Networks

A substantial body of research has been undertaken in extracting useful metaphors from the neural systems. Artificial Neural Networks are parallel distributed processing systems that are constructed via the connection of simple processing known as artificial neurons [7]. ANN have been applied to a vast array of problem areas such as machine vision [11]and robot control [10]. Figure 1 is a graphical depiction of a simple artificial neuron. In order to be of any practical use, individual neurons are connected together to form artificial neural networks. These networks are *trained* in order to be able to classify input

patterns (x) through the constant adjusting of the weights (w_i) until the ANN can recognise the pattern. The weights are adjusted via a number of possible *learning algorithms* e.g. backpropogation. An artificial neuron can be represented mathematically as shown in Equation 1. Once the summing of the inputs has taken place, the neuron will fire, depending on the activation function $f(u)$, in this case of work in this paper a standard sigmoidal activation function has been employed, as shown in equation 2.

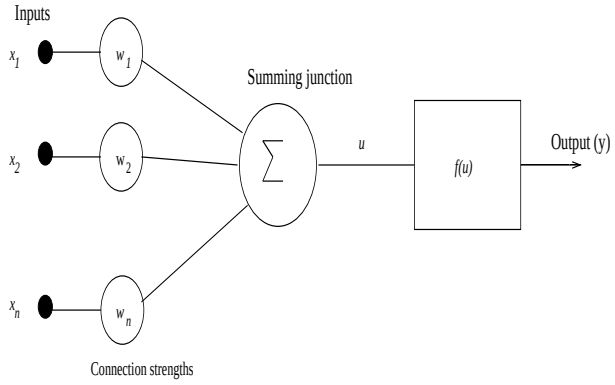

Figure 1: A simple artificial neuron

$$u = \sum_{i=0}^{nx} w_i \cdot x_i \tag{1}$$

$$f(u) = \frac{1}{1 + e^{-u}} \tag{2}$$

Work in this paper proposes to augment this basic artificial neuron, with interactions from an artificial endocrine system. For the purposes of this work, the weights within the ANN are constant, although for future work, this will not be the case.

3.1.2 Artificial Endocrine Systems

This paper proposes a new biologically inspired technique known as an Artificial Endocrine System. The role of the AES is to provide a long term regulatory control mechanism for the behaviour of the system. The AES proposed consists of *gland cells* which secrete *hormones* in response to external stimuli, to the value r_g for one gland g. This is shown in equation 3 where α_g is the rate at which hormones are released for a particular gland g.

$$r_g = \alpha_g \sum_{1=0}^{nx} x_i \tag{3}$$

The level of hormone is subject to geometric decay, as shown in equation 4 where $c(t)_g$ is the hormone concentration at a time t for a gland g and β is the decay constant.

$$c(t+1)_g = c(t)_g \cdot \beta \tag{4}$$

Membrane receptors located on artificial neurons are sensitive to hormones, thus providing a mechanism for the regulation of the ANN by the AES. Gland cells secrete and record the concentration of hormones present in the system. Each gland cell secretes a specific hormone, represented by a simple string of bits. Within the integrated AES-ANN the hormone sensitive membranes of neurons simply have a list of hormone receptors (again, represented as bit patterns) to which hormones are matched and a neuron-specific action associated with each receptor. At present, perfect matches of hormone to receptor are considered (though this is not necessarily required: imperfect matches should generate lesser reactions). In the natural endocrine system, hormones are transported throughout the body: the same effect is achieved in the AES through the matching of each hormone secreted to the receptors on each cell's membrane in turn. A record of the current concentration of a hormone is maintained in the gland cell which secretes the hormone, and is then used to moderate the strength of reaction.

True to the analogy with the biological endocrine system, different cells types react to particular hormones, in different ways. The actions which are triggered in individual cells can vary according to four factors: the hormone which is detected, its concentration, the type of receiving cell and the individual cell's make-up. The former two of these factors are explained above, but the latter require further explanation. The type of cell receiving the hormone signal will clearly dictate what actions it is capable of performing. For example, a neural cell may lower (or raise) its threshold value or increase (or decrease) its sensitivity to one or many of its inputs; and a gland cell may increase (or decrease) secretion rate of a hormone. The precise make-up of cells is fixed when they are added to the system. This may include variations in membrane characteristics (abilities

to receive hormone signals), the effects that those signals have within the cell and other cell-type-specific characteristics such as connectivity pattern of a neuron etc.

In order to allow for the AES-ANN interactions, the hormone levels have to be able to affect the input weights in the ANN. Figure 2 provides a simple graphical representation of how this is achieved. Here the recorded hormone level affects each input weigh on a particular neuron. It is easier to see this when these interactions are described mathematically, as in equation 5, where in this case x_i and w_i are the same as equation 1 and ng is the number of glands in the system, C is the concentration of hormone, S is the sensitivity of the connection for receptor i to hormone j and M is the match between the receptor i and hormone j and is defined in equation 6, where dis is a distance measure function.

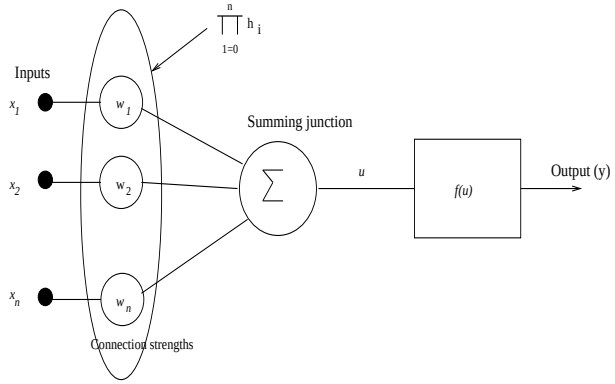

Figure 2: The affect of endocrine interaction on the artificial neuron

$$u = \sum_{i=0}^{nx} w_i \cdot x_i \cdot \prod_{j=0}^{ng} C_j \cdot S_{ij} \cdot M_{ij} \qquad (5)$$

$$M = \frac{1}{1 + dis(i,j)} \qquad (6)$$

It is now possible to compare equation 1 with equation 5. It should be noted that the new equation for the AES-ANN interaction is simple augmentation of the original equation, with the iterative application of hormone levels applied to each input weight in the neuron. It should also be noted that this new AES Neuron bares a passing resemblance to the *Sigma Pi Neurons* [9], it is fundamentally different upon further examination.

3.1.3 Artificial Immune Systems

AIS is very much an emerging area of biologically inspired computation. This insight into the immune system has led to an ever increasing body of research in a wide variety of domains such as machine learning [13], immunised fault tolerance [4] and computer security [6] to name a few. Recently, an attempt has been made to bring together what at times seemed a disparate area of research, in a general AIS framework which describes basic AIS components, interactions and algorithms [5]. Here the authors argued that AIS could be seen as a novel soft computing paradigm that has great potential to be hybridised with a variety of other soft computing approaches and computational intelligence paradigms.

It is anticipated that in future work, an AIS will be integrated into the mechanism, described here and will interact with both the ANN and AES to maintain homeostasis.

4 Target Application for ANN-AES Interaction

In order to test some of the mechanisms proposed here, a simple artificial neural system and artificial endocrine system were implemented. The chosen application was a controller for a mobile robot in an office environment. The robot (a Pioneer 2DX[1]) is equipped with 16 sonar sensors arranged around its perimeter, which are capable of detecting objects reliably up to about 5 metres away. A simple neural network was initially set up manually to link these sensors to the motors which drive the wheels. The network generates simple object avoidance behaviour which works effectively in a static environment. Network weights were chosen manually and adjusted after experimentation to maintain reasonable clearance when approaching and avoiding objects. The network was supplied with a bias node which was used to ensure that there was sufficient activity in the output nodes to generate forward motion when there was no stimulation of any of the sonar sensors. The resultant behaviour observed was "wandering" whilst avoiding walls and other objects. Typically when a wall was approached, the robot would gradually turn by an angle close to 180 de-

[1] http://robots.activmedia.com/

grees and move off in a straight line until it encountered the next obstacle.

This behaviour became inadequate when dealing with a highly populated environment. The robot became very close to some objects and upon occasions collided with them. A "more cautious" set of weights for the neural network would have eliminated the problem, but would then have made the behaviour unnecessarily cautious in less cluttered environments. For some tasks such as automated floor cleaning or map building this would be undesirable as it would leave larger than necessary regions of the environment unexplored. Thus, the alteration of the distance to which the robot would approach obstacles became a candidate for the application of hormonal control.

4.1 Mechanisms for Implementation

The ANN and AES employed in the implementation of the robot controller are as described in sections 3.1.1 and 3.1.2 respectively. In this implementation, which was designed to investigate the functionality of the AES, there was no weight update mechanism (learning) employed in the neural network.

The controller was compiled and run on a PC104 embedded personal computer (running RedHat Linux) physically mounted inside the robot itself. The PC104 board uses a serial connection to communicate with a low-level microcontroller which drives the motors and services the sonar sensors employed. Communication with the embedded PC104 is via a radio-ethernet link.

Figure 3 provides a graphical illustration of the implemented system. The ANN is fully connected and no weight adaptation mechanism is employed at this stage. Similarly, hormones and receptors are fixed in length and content. Artificial neurons receive input from sensors, as does the artificial endocrine gland. When a stimulus is encountered, the artificial endocrine gland excites or inhibits each synapse in the ANN (as illustrated by the shaded area) via the hormone release mechanism, see equation 5. The hormone (which might be seen as analogous to a hormone such as adrenalin) was excitatory to all synapses (or weights). The activation level of the two output neurons is then used to drive the motors directly.

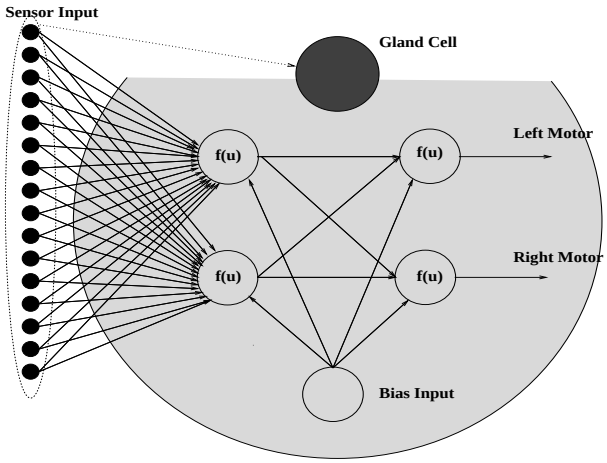

Figure 3: The Artificial Neural Network augmented with the Artificial Endocrine Gland. There are 16 sensor inputs, 2 hidden layer nodes and 2 output nodes. Each output node controls either the left motor or right motor control. The shaded area indicates that the hormonal gland influences the neurons in the network

4.1.1 Experimental Setup

The robot was run in the Intelligent Systems Laboratory at Aberystwyth in a relatively constant, but uncontrolled environment. The robot was placed in the same start position and orientation for each run. The start point was at the centre of an approximately square region of floor (approximately 6 metres across) bounded on two sides by desks and chairs, on one side by a wall and on the fourth side by a wall with narrow openings at each end which lead into short cul-de-sac corridors.

4.1.2 Experimental Method and Aims

In order to examine the effect that the endocrine interactions were having on the behaviour of the robot, a series of experiments were performed. The robot was run for 22 minutes at a time after which results were downloaded and the robot returned to the start position.

Three different versions of the controller were used. The first was the pure ANN implementation in which the hormone was not allowed to interact with synapses at all. This is intended as a control. A second version was given a fixed level of hormone throughout the experiment and was used to ensure that the hormone was having the intended effect on the behaviour of the robot. The

third version was given a complete implementation of the AES in which the endocrine cell was connected to the sensors and released more hormone when the sensors were more stimulated (ie. obstacles were closer). Each experiment was run 5 times in order to investigate the variability of performance and to lend statistical weight to the results.

Thus the aim of these experiments was to show that:

1. Higher hormone levels result in a more expeditious retreat from obstacles
2. The variable hormone release mechanism is effective in allowing both close approaches and expeditious retreats

4.1.3 Results

Table 4.1.3 shows results from all fifteen experiments performed. The activity of a sensor is calculated as follows:

$$sa = 1 - dist \tag{7}$$

where sa is the sensor activity as presented to the ANN and AES, and $dist$ is the distance (in metres) to the nearest obstacle as detected by that sensor. Due to the small size of the space in which the robot was operating any objects more than one metre away were ignored.

The table shows the summed activity of the most active sensor over complete runs. It is clear from the values in the table that when equipped with the controller with no hormone present the robot spends much more time in close proximity to obstacles than when the controller either has a fixed high level of hormone or a variable level of hormone. It is also clear that the values observed are (despite some variability between repetitions) significantly different under the different regimes.

Thus by examining the first two columns of the table we can confidently assert that higher hormone levels do result in a more expeditious retreat from obstacles.

Figure 4 shows the activity of the most active sensor at the beginning of three runs (one with each version of the controller). The first approach to the wall, represented by the first increase in sensor activity, clearly shows the differences between the behaviour induced by the three controllers. The controller with no hormone present

Integrals of sensor activities			
Hormone Regime	**Zero**	**Fixed**	**Varying**
	8217	3153	4617
	7435	3083	5066
	9576	4495	4714
	14421	2514	5023
	10211	4439	4509
Average	9972	3537	4786
St. Dev.	2717	885	247

Table 2: Integrals of sensor activities under various hormone regimes

spends three times as long in range of the obstacle as the fixed hormone level controller, and a little more than twice as long within range than the variable hormone controller. Of most interest however, is that the controller with a variable hormone will approach obstacles to a similar distance, when compared to the controller without any hormone. It then will beat a hasty retreat. This seems to provide evidence that the second aim, as stated above, is also achieved.

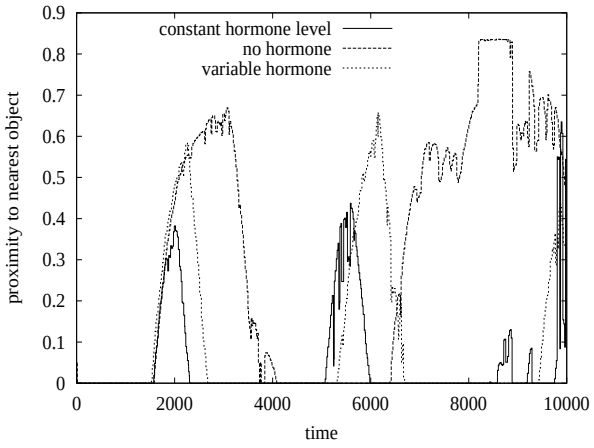

Figure 4: Example sensor readings under three different hormone regimes

Figure 5 shows the hormone level from a specimen run of the robot under the variable hormone regime. The release of hormone as the robot approaches obstacles can clearly be seen as marked "spikes" in the upper trace. The region marked as "negotiating corridor" marks a period of time in which the robot entered one of the cul-de-sac corridors, manoeuvered to the end of it turned

around and moved out of it again. The close proximity of the walls whilst the robot is in the corridor maintains a raised level of hormone for a prolonged period during which the robot avoids approaching walls too closely. Figure 6 shows the path taken by the robot on this occasion (only the period between entering the corridor and leaving the corridor is shown). It can be seen that the trajectory taken by the robot under a variable hormone regime covers about 1 metre of the corridor's width. Figure 7 shows a similar portion of the robot's trajectory whilst under control of the fixed hormone level controller. On this occasion it can be seen that the trajectory covers only about 70cm of the width of the corridor. The skewed nature of the trajectory with respect to the walls as drawn (especially in figure 7) is due to wheel slippage allowing errors to build up in the dead-reckoning used to keep track of the robot position. Future work will be undertaken using a motion tracking system to eliminate such problems.

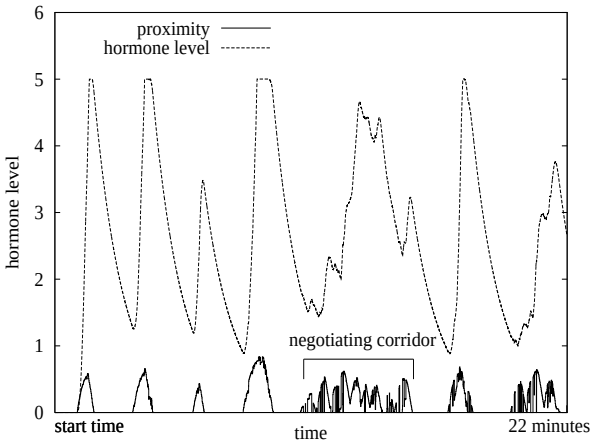

Figure 5: Recorded hormone level for an example robot run

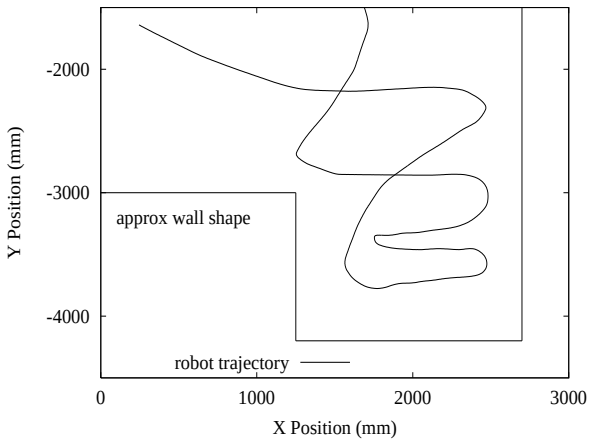

Figure 6: Negotiating a corridor under the variable hormone regime

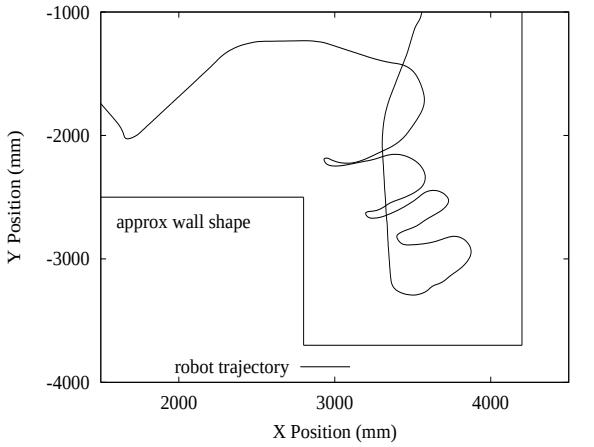

Figure 7: Negotiating a corridor under the fixed hormone regime

4.2 "Emotional" Response

Informal experimentation with the robot (whilst running the variable hormone level controller) was carried out which involved "trapping" the robot between the arms by blocking the sensors at very close range. This initially caused the robot to stop moving forward and to turn around "looking for a way out". If the trapping was continued for a long period of time the robot gradually became more and more rapid in its movements and eventually it would spin at maximum speed on the spot. As soon as the blocking of the sensors stopped it would head away from the torturer on an erratic path into an open space. Pursuing the robot or obstructing its path whilst the hormone level was still very high resulted in very violent turns away from the obstruction. Over a period of a couple of minutes the robot would "calm down" as the hormone level reduced. Presentation of these results is extremely difficult in anything approaching a scientific manner, and until the authors have found a way to do so we will not attempt more than an informal description such as this.

It is worth noting however that people's reac-

tions to this "torturing" of the robot are interesting in their own right. Requests to "leave the poor thing alone" and other such comments are not uncommon. Indeed it is surprising how people are very willing to project emotions onto a small autonomous robot which exhibits even very rudimentary displays of "distress" and"fear".

The notion of projecting emotional states onto the robot is one with which the authors are a little uncomfortable, but we feel it is our duty to put our philosophical/psychological stance on display. Of the various philosophical theories of emotion we (in broad agreement with [8]) identify three plausible candidates at a level appropriate for consideration with respect to this work. Versions of an epiphenomenal theory which are often attributed to Hume and Descartes seem to rely on self-awareness and the ability to report *feelings* and thus lack credibility in this case due to the level of intelligent reporting and introspection that they seem to require. Such theories also lack a causal route between the emotions and actions which would seem to be fundamental to the attribution of emotional state in mechanisms as simple as that embodied in our robot. A theory which is arguably more suited to the mechanisms present in our robot is one that was put forward as a part of the (now largely disregarded) behaviourist stance. This theory states that an emotion is "*an hereditary 'pattern-reaction' involving profound changes of the bodily mechanism as a whole, but particularly of the visceral and glandular systems*"[17]. This biological level of description is appealing, but there are several problems with the repercussions of the *hereditary* qualifier which makes this a particularly weak candidate theory (see [8] for discussion). The third (and favoured) theory is a version of a cognitive theory originating from the Greeks (and especially Aristotle[1]), which proposes that emotions are evoked in response to beliefs about the state of the world and possible events which may be caused by that state in the future. Thus whilst we are not entirely comfortable about assigning the word *belief* to the state of the neurons in the robot when presented with obstacles in the world, this is the point at which we feel most comfortable about making a stand. Thus we should say that the control system as a whole (through the belief that an object close to the robot presents a risk of collision) acheives a level of fear via the response of the gland cell releasing the hormone. This modifies the behaviour of the robot in a way consistent with "fear" which in turn results in timid behaviour. Thus the "fearful" state of the robot is caused by and displayed by the internal state of the robot and its interactions with the environment. We do not propose that this is the only or even the best philosophical explanation of how the controller works, but believe that this explanation captures the spirit in which the controller was constructed.

The results as presented above show a potentially useful application of an artificial endocrine mechanism in moderating interactions with obstructions in the environment of a mobile robot. Ascribing an emotion such as "fear" or "timidity" to this mechanism seems like a reasonable approach to describing the behaviour that is generated. Although the mechanism used is extremely simple, the behaviour generated is both functional and emotively appealing.

5 Conclusions

A mechanism for the integration of ANN and AES models has been presented. This is set in a wider context with respect to homeostatic mechanisms. An example implementation of a robot controller which embodies this mechanism is detailed and results demonstrating its behaviour and performance are presented. The behaviour shows traits which may be useful in exploratory behaviour, especially in varying environments. The behaviour is also appealing subjectively and elicits responses from onlookers who are willing to ascribe emotional states to the robot.

Future work will involve use of precision motion tracking software and more complex controllers involving more than one hormone. Research into more complete models of artificial homeostasis is also on-going.

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